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The Honourabl[e]
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Curriculum Guideline

Technological Studies

Intermediate and Senior Divisions

Part C
Ontario Academic Courses

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Contents

Introduction

The technological studies curriculum guideline consists of three parts: *Part A: Policy for Program Planning*, Part B, which is structured into ten subject groupings, and *Part C: Ontario Academic Courses (OACs)*. Part A provides essential background for the planning of all courses in technological studies. The following three sections in Part A are especially important in this regard: "The Aims of Technological Studies", "Program Requirements", and "Course Planning at the Department Level" (including the evaluation of both student achievement and the program).

Part C consists of three course guidelines that provide authority for Ontario Academic Courses (OACs) in technological studies. Each guideline authorizes a single-credit course. The subjects of the courses are computer technology – interfacing, analog and digital electronics, and fluid power and control.

Although the technological contents of the courses differ, the learning opportunities and outcomes are similar. Within the context of the particular field of technology, students will develop their abilities in the areas of problem solving, independent study and investigation, communication on technological subject matter, and working with hardware. In each course, the design process provides a focus for this learning. Technological solutions can take a wide range of forms. Starting with the analysis of commercially available solutions for specific problems, students will develop the skill and knowledge that will enable them to design unique solutions to other problems. But the process does not stop there: students will then assemble hardware in accordance with their designs.

Many technological concepts are common to all three courses, although each course presents them from its own perspective. Examples of such concepts are logic, feedback, selectivity, sensitivity, systems design, energy transfer, sequencing, and timing. In all the courses, these concepts are explored through a combination of abstract learning and functional applications of hardware associated with the particular technology. When students understand these concepts sufficiently to apply them to other subjects, a significant educational goal has been attained.

Rapid development in the fields of communication, automation, and robotics has created a need for the hands-on learning that technological OACs provide. The insights that students gain through these courses will benefit not only those who are planning careers in technology but also anyone who will have to cope with technological change. Each OAC is planned to support a range of career opportunities and to give students the background they will need if they decide to pursue further education.

Subject sections

A separate section is provided for each OAC. Each section includes an introduction to the subject field, the course aims, suggestions for planning the course, and an outline of the course content. The course content is developed under three headings: "Overview", "Objectives", and "Teaching Notes".

The "Overview" subsection indicates, in chart form, the approximate course time to be allocated to each of the units. These times reflect the relative emphases to be placed on the units to ensure adequate coverage of the specified content. It is assumed that the units will be offered in the numerical sequence indicated.

The subsection headed "Objectives" specifies the major course objectives that students are expected to achieve. These course objectives, numbered 1.1, 1.2, etc., are supplemented by enabling objectives, which are also numbered for reference. In the case of the major objective 1.1, for example, the enabling objectives are 1.1.1, 1.1.2, 1.1.3, etc.

In general, to achieve a major objective, the student must meet all of the associated enabling objectives. The numerical order of the objectives is only a suggested teaching sequence; within any one unit, both major and enabling objectives may be ordered by the teacher to suit a particular teaching strategy.

The items in "Teaching Notes" are numbered to correspond with the objectives in the "Objectives" subsection. These two subsections should be used in conjunction. The notes indicate which concepts need to be developed and reinforced, suggest teaching strategies for accomplishing the objectives, and offer other suggestions concerning the planning and delivery of the course.

Evaluation
Comments about the evaluation of student achievement and some suggestions concerning the evaluation of programs in technological studies are outlined on page 24 of *Technological Studies, Part A: Policy for Program Planning*.

Marks on post-tests and projects should be considered in summative evaluations of student achievement in Ontario Academic Courses. The following weighting of marks is suggested: laboratory work, 35 per cent; theoretical knowledge, 45 per cent; and individual project/term assignment, 20 per cent.

Every student enrolled in an OAC in technological studies must write at least one formal examination for that course. Formal examinations should reflect the relative emphases on the various objectives within the course (as indicated by the time allocations for each unit). The results of formal examinations shall constitute not less than 35 per cent of the summative assessment for each OAC in technological studies.

It is imperative that each student be made aware of the evaluation criteria at the outset of the course. These should be given to students in writing and discussed with them at an early date.

Laboratory work can be assessed for completeness, accuracy of results, and quality of reporting. The acquisition of specific theoretical knowledge can be determined by tests and examinations. Because the major projects or term assignments that a student chooses to undertake may be different from those of other students (varying not only in its topic but also in its objectives and depth of treatment), a marking scheme must be devised for each potential project and made available to students when they choose their project. Assessment of projects should include a measurement of the student's success in learning technological content through independent reading and investigation. Improvements in critical thinking and communication skills, as reflected in the student reports on these project assignments, should also be recognized in the assessment.

Students enrolled in OACs are mature enough to be involved in the establishment and validation of assessment criteria, particularly for laboratory and project assignments. If students help to choose their assessment criteria, they are more likely to feel that the criteria are valid and that the final mark is fair.

Computer software
In each of the Ontario Academic Courses outlined in this document, the use of microcomputers is part of the course content. Students will design computer-controlled applications for electrical, mechanical, or fluid power systems, doing in-depth analyses of the microprocessor functions required for adaptation and design of software and/or hardware.

As computer software related to electronics, computer technology, and fluid power and control becomes available, teachers should adjust their teaching strategies to take advantage of it. Applied at appropriate times, computer programs can help the teacher to teach, reinforce, and review information and test students' understanding of it.

A prerequisite for enrolment in the courses described in this document is some ability to write, in a high-level language, simple programs for applications involving electrical circuit theory, mechanics, and/or the physical principles governing fluids. Courseware related to these knowledge areas, under development for the Ontario Approved Educational

Microcomputer (OAEM), and other related courseware designed for available microcomputers offer an effective way for students to acquire and/or review this learning independently. Learning activities of this type need to be reinforced by hands-on experiences with appropriate materials, tools, and equipment.

Students should have opportunities, through assignments wherever possible, to become aware of the various tasks that computer technology performs in the manufacturing sector.

Visits to manufacturing plants and institutional training centres can provide useful insights into the use of computer-aided manufacturing (CAM) and other automated processes.

Computer Technology – Interfacing

This guideline provides authority for offering a single-credit Ontario Academic Course (OAC) in the technological studies field of computer technology. The course focuses on the technology for interfacing computer-controlled devices with the computer.

Although the computer itself operates on an elementary digital on-off principle, the number and speed of digital "decisions" are extremely high. The integration of thousands of components into a single package at relatively low cost has spurred the use of computers over the past twenty years. Today it appears that the potential applications of computers and computer-controlled devices are unlimited; new areas of use appear with increasing frequency, and costs continue to decline.

Computer-controlled devices must be connected to the computer by interfacing circuitry of appropriate design. There is a wide range of interfacing techniques available to implement new practical applications as they are developed.

As the use of computers and computer-controlled devices expands into all facets of the workplace, the need for people who can design, produce, and/or use the interfacing technology of electronics and programming continues to grow. The understanding of computer interfacing that students acquire in this course provides a useful base for further studies as well as for work activities in this field.

The prerequisite for this OAC is mathematics, Grade 11, advanced level, or its equivalent. In addition, students should have acquired, or should be prepared to acquire independently, the ability to write simple programs in a high-level language.

The course code for Computer Technology – Interfacing is TEI0A.

Aims

Students who enrol in this course will have the opportunity to:

- acquire basic skills and knowledge in the technological field of digital computer interfacing;
- determine their aptitude for and interest in further studies in this field;
- develop the processes of logical thinking and creative problem-solving through the analysis and design of interfacing circuitry;
- hone their skills in written and oral communication, critical thinking, and independent study in the course of designing, testing, and reporting on computer-controlled applications.

Suggestions for Planning the Course

The minimum time required to accomplish the performance objectives (core content) listed in the course outline is 100 hours. If the core content is accomplished in the minimum time, additional project assignments based on unit 5 may be undertaken by students for the remaining course time.

In preparation for unit 5, students should be informed early in the course that they will be required to select and complete (through independent study and creative effort) a project in one or more of the areas listed in that unit.

This course involves the student in a mix of theoretical study and practical learning experiences. The course should include regular laboratory classes of at least one hour's duration.

The development of good safety habits is an important part of the laboratory work in this course. A discussion of safety is included in Part A of this guideline as a topic under "Program Requirements". Hazards and injuries that students must learn to respond to include the following:

- electrical shock;
  Contact with 120-V power lines can cause lung paralysis or heart fibrillation; knowledge of artificial respiration and defibrillation techniques is highly desirable in such an emergency.

- fires;
  Students should know the proper procedures for dealing with fire, including the selection and use of proper extinguishing means.

– chemicals;
Students should be aware of the presence of toxic chemicals that can burn, injure, or poison and of the best immediate treatment of injury.

– burns.
Students should know how to administer first aid.

Students should be made aware, very early in the course, of the specific programming skills they will need in order to accomplish objectives such as 1.3. Students who need to review or acquire these programming skills should do so independently, with guidance from the teacher as necessary.

Course Content

For a detailed discussion of how to use this section, see pages 1-2 of this manual.

Overview

Content Units	Course Time (in hours)
1. Introduction	10
2. Digital interfacing	25-30
3. Analog interfacing	35
4. Data communications	10-15
5. Computer-controlled applications	20-30

Objectives

1. Introduction

Students will have the opportunity to:

1.1 observe how a microcomputer controls a variety of devices by sensing various external signals; observe the microcomputer's use as a dedicated device, such as a waveform generator;

1.1.1 using block diagrams, show which components of the system are responsible for sensing and controlling processes;
1.1.2 use a block diagram that indicates the main parts of the microcomputer, such as the clock, RAM and ROM memory, address and port decoding, and I/O device interfacing; trace the routing and processing of input and output signals to the device or peripherals;
1.1.3 follow a clearly written flow chart or sequencing diagram that describes unambiguously the operation of the system, in order to interpret the sequence of steps indicated by the application program controlling the system;
1.1.4 observe a demonstration of one or more dedicated applications of a microcomputer;
1.1.5 identify the transformation of analog and digital signals within the interface circuitry;
1.1.6 discuss the breadth of present and potential applications of computers, especially as they involve control of real-time events;

1.2 acquire an understanding of binary and other number systems currently used in computer technology and be able to convert from one system into another;

1.2.1 describe how different number bases are used in computer technology;
1.2.2 convert from one number system to another;

1.3 program the microcomputer for laboratory exercises and construction projects;

1.3.1 use a high-level language to program the microcomputer to perform real-time control activities;
1.3.2 use machine language or assembler programming for real-time control in those situations where a low-level language has distinct advantages;
1.3.3 program the periodic waveform generator, using both high-level and low-level languages, in an endless loop, and observe waveforms on an oscilloscope;
1.3.4 calculate the period of the generated waveforms using available documentation on the instruction set.

2. Digital Interfacing

Students will have the opportunity to:

2.1 construct a microcomputer interface to control a simple external device;

2.1.1 control one or more devices using the output ports of a microcomputer;
2.1.2 analyse the hardware of external devices and write software to control them;

2.2 construct a microcomputer input interface to sense the state of an external device;

2.2.1 control one or more devices on an output port by sensing one or more switches on the input port;
2.2.2 analyse the hardware and the program that are used to sense and control external devices;

2.3 construct a microcomputer interface, using feedback, to sense and control an external process;

2.3.1 construct and test a microcomputer-based counter that counts external events and displays the count;
2.3.2 construct and test an interface to control the position of an external device, such as a DC motor that can be stopped or reversed after a predetermined number of steps;
2.3.3 construct and test an interface that achieves speed control of a DC motor, using pulse width modulation and a feedback loop that incorporates Hall field effect sensors;
2.3.4 construct and test an interface, containing a feedback loop, that can be used to change the position of an external device, such as a relay, motor shaft, or robot;
2.3.5 analyse the hardware and the programs used to accomplish 2.3;

2.4 use parallel interfacing to demonstrate encoding and decoding of information external to the microcomputer;

2.4.1 connect a bank of switches to a parallel port to demonstrate encoding;
2.4.2 attach a commercial encoded keyboard and sense the key-press bit to determine when data should be read;
2.4.3 connect a device, such as a latching light-emitting diode (LED) or printer, that will decode the output of a parallel port;
2.4.4 analyse encoding and decoding in terms of hardware, software, and block diagrams, with emphasis on hardware and software trade-offs;

2.5 investigate methods and applications involving timing as a control parameter;

2.5.1 program an interface that detects the occurrence of an external event;
2.5.2 program an interface that causes an external event to occur at a predetermined time;
2.5.3 program an interface that measures the number of external events per unit of time;
2.5.4 analyse the hardware and programs used to accomplish 2.5.

3. Analog Interfacing

Students will have the opportunity to:

3.1 build, and analyse the operation of, a simple digital-to-analog (D/A) converter;

3.1.1 discuss, construct, and test a simple D/A converter that demonstrates the essential operations performed by all D/A devices;
3.1.2 construct and test an operational amplifier circuit in order to demonstrate the performance capabilities of the device;
3.1.3 analyse the abilities and limitations of a simple D/A converter in the domain of waveform synthesis;

3.2 use, and analyse the operation of, commercial D/A converters;

3.2.1 wire and test one application using a commercially available D/A converter; observe waveforms, using a voltmeter and oscilloscope;
3.2.2 investigate the range of possible applications for D/A converters, stressing speed, resolution, and cost;

3.3 build, and analyse the operation of, a simple analog-to-digital (A/D) converter;

3.3.1 study a block diagram that shows the basic elements of a simple A/D converter;
3.3.2 construct and test an analog comparator that has digital output, in order to demonstrate the capabilities of that device;
3.3.3 use a comparator with the D/A to make a simple counting converter;
3.3.4 analyse the abilities and limitations of a simple A/D converter, especially with regard to speed and resolution;
3.3.5 write a computer program to drive the simple A/D converter;

3.4 use, and analyse the operation of, commercial A/D converters (ADCs);

3.4.1 using a commercial ADC, observe the digitized output for various levels of analog voltage input;
3.4.2 investigate the range of possible applications for A/D converters, and select an appropriate ADC for a given application;

3.5 investigate a variety of transducers that may be used in sensing and control circuits;

3.5.1 observe and measure the transduction characteristics of transducers such as thermocouples, thermistors, photovoltaic cells, piezo-electric crystals, strain gauges, Hall effect devices, speaker-as-displacement devices, DC generators;
3.5.2 investigate the range of possible applications for each of the transducers studied in 3.5.1;

3.6 analyse, design, and build closed-loop systems;

3.6.1 build, and test the operation of, a closed-loop system that employs transducers and both A/D and D/A conversion in conjunction with a microcomputer;
3.6.2 analyse in depth the operation of a complete closed-loop system of the type used in industry;
3.6.3 design a variety of solutions to problems, using the elements employed in 3.6.1.

4. Data Communications

Students will have the opportunity to:

4.1 investigate methods of communication between computers;

4.1.1 examine the ASCII code used for serial communications;
4.1.2 use a UART in software (and minimal hardware) to transmit and accept a byte of information in ASCII at a 2400-baud rate;
4.1.3 interconnect two computers and have them transfer a few bytes of information using the standard RS-232 asynchronous communication protocol;

4.2 analyse the functions of one or more computer networks, and demonstrate their capabilities where possible;

4.3 discuss the use of modems to convert RS-232 signals for transmission over telephone lines and, if possible, demonstrate;

4.3.1 differentiate between various levels of sophistication in modem operation;
4.3.2 examine one or more methods of modulation/demodulation.

5. Computer-controlled Applications

Students will have the opportunity to:

5.1 develop an individual project/term paper in one or more of the following areas:

5.1.1 remote sensing and control;
5.1.2 gathering and collating of data;
5.1.3 computer-controlled audio-visual equipment;
5.1.4 pattern recognition;
5.1.5 process control, involving transducer sensors;
5.1.6 peripherals;
5.1.7 graphics;
5.1.8 voice synthesis;
5.1.9 alarm systems;
5.1.10 CAD/CAM;
5.1.11 robotics;
5.1.12 data communications systems;
5.1.13 computer-generated waveforms;
5.1.14 software engineering;
5.1.15 UART design and operation, including handshaking.

Teaching Notes

The numbers of the teaching notes correspond to the numbers of the objectives in the preceding subsection. The two subsections should be used together in the planning of this course.

1.1 The important concepts to develop and reinforce are: interfacing, computer architecture, programming, analog and digital signals, real-time control, and peripherals.

- The teaching strategy for this unit can be mainly teacher demonstration and discussion.
- A block diagram that matches the features of the computer and the controlled devices being demonstrated should be drawn by the teacher and used to help students comprehend the system.
- In particular, students should note the input-to-output (I/O) relationship; for example, the computer merely senses the status of external inputs, whereas for output it must latch the data.
- The teacher should have available hard copy of the programming being used for the demonstration. If possible, the programming should be displayed on a large monitor for all to see. Particularly useful is a utility that will trace the computer operations step by step and display them on the CRT.
- The importance of good documentation of software should be stressed.
- The difference between analog and digital signals may need to be reviewed. A brief program can be written that will display these on the monitor, using a sine wave and a positive-going pulse train. The need for A/D and D/A converters will become obvious as the demonstration progresses.
- The teacher should have the computer generate continuous sawtooth waveforms by incrementing a counter, storing the output to an eight-bit DAC, and looping.
- Not more than one hour should be devoted to item 1.1.5.

1.2 Important concepts are number bases (binary, decimal, hexadecimal) and conversion.

- The need for conversion between binary and other number systems should be recognized by students. Arithmetic and logic operations within the computer are done in binary, whereas programmers use decimal or hexadecimal number systems for convenience in their design work.

1.3 Important concepts are high-level and low-level languages, real-time control, compiler, and assembler.

- Both high-level and low-level languages are important; each has its place.
- Students who have not previously acquired high-level-language programming skills and are developing them on their own may demonstrate achievement of objective 1.3 by completing increasingly difficult assignments over the period of the course.
- As coursework progresses, students should be required to write pertinent programs that are formed by some combination of simpler programs written earlier.
- Where a low-level language is used, the teacher will provide short demonstration programs; students will be expected to demonstrate their comprehension by modifying these programs.
- Students should be aware that, subject to hardware limitations, real-time process control can be accomplished using high-level languages alone; however, if high-speed process control is required, assembler programming must be used.
- Students should be shown the relationship between the time required to complete an instruction and the computer's clock speed.

2.1 Important concepts are pulse signals, buffering, interfacing, on-off control, computer ports, and isolation.

- *Construct* means to assemble on a quick-connection board; no soldering is involved.
- The *external devices* can be LEDs, preferably latched LEDs activated by simple address decoding or port call.
- A more detailed explanation of what constitutes a *computer port* is required at this point.
- Although PIAs may be used here, note that they are not being incorporated in new designs.
- The demonstration program can be in both high-level and low-level languages.
- The teacher should explain the reason for, and the importance of, adequate buffering and isolation in the design of interfaces.

2.2 Important concepts are digital clock, sensing, and real-time control.

- Switches can be manually operated, or input pulses can be supplied by a simple clock running at a low frequency.
- Several on-off sensing devices that can be used to trigger computer action should be available.
- Tri-state devices can sense external conditions instantaneously; therefore, they do not lock the computer continuously to the sensing task.
- Here again, the demonstration program can be in high-level and low-level languages. It will be possible to show the difference in speed of operation, even with a short program.

2.3 Important concepts are feedback loop, counter, display, and stepping motor.

- The teacher should select specific circuitry and devices from current technical literature and textbooks.
- The switching devices can extend to transistor or op-amp switching circuits, or gates that are triggered by some external event.
- Among the possible controlled devices are a solenoid and a small DC motor.
- The teacher should stress the superiority of performance of the closed-loop systems over the open-loop systems.
- Hall field effect devices are available from several sources. These devices are superior to optical devices in their simplicity and reliability.

2.4 Important concepts are memory, encoding, decoding, and hardware-software trade-offs.

- Students should be aware that several codes are commonly used.
- Keyboards typically employ the ASCII code.
- LEDs can be used as inexpensive means of displaying encoded results.
- The two methods of sensing input – polling and interrupts – should be explained.
- Students should construct and test an interface that operates an output device, e.g., an interface that turns on an LED when a particular SIN code is entered.
- The trade-off between hardware and software in the design of interfacing solutions makes a good topic for group or class discussion.
- Students should be told why dot matrix parallel printers require handshaking.

2.5 Important concepts are clocks, timing synchronization, pulse width modulation, and rate.

- Students should have some understanding of the mechanism and programming by which computer timing is accomplished.
- If a clock signal is used to provide a rapid source of "events", the speed of the computer, acting as a counter, can be demonstrated; one has, in fact, a sort of one-shot frequency counter.
- Loop cycles can be counted and converted into real time by multiplication of the number of loop cycles by the duration of each loop.
- Simple programming will permit an external device to be started or stopped when a predetermined number of clock pulses has occurred.
- The computer is able to perform like a very high Q filter, using clock cycles and frequency of the selected wave.
- Group discussion is appropriate for analysis of the hardware and programming used in this unit.

3.1 Important concepts are D/A conversion, faster scanning, waveform synthesis, number systems, feedback, and gain.

- A loudspeaker can be connected to an output port of a computer that has been programmed to supply pulses; the speaker will transduce the pulses into tones of various frequencies.
- Students should be able to describe the process by which the speaker operates.
- A four-bit ladder resistor network, manual switches, and an op-amp can be used to demonstrate the function of a D/A converter.
- Rapid switching of digital input will produce a crude synthesized waveform. A bit generator operating at various frequencies should be used to supply the digital input.

3.2 Important concepts are resolution, design, and digital-to-analog conversion.

- The teacher should make up a block diagram of a commercial circuit and then analyse the circuit itself. An example would be a raster scan generator employing an "X" DAC and a "Y" DAC.
- If time permits, students should build, and analyse the operation of, the raster scan generator.
- The role of operational amplifiers (as voltage level changers in a D/A converter) should be analysed.
- Students should refer to manufacturers' specifications when comparing performance characteristics.
- Students should reach informed conclusions about the relative merits of various chips and circuits for D/A purposes, on the basis of vital criteria and technical facts.

3.3 Important concepts are A/D conversion, comparators, and methods of approximation.

- The teacher should illustrate the operation of the A/D converter with a block diagram before proceeding to the circuit details.

- There are several simple (single chip) means of accomplishing A/D conversion.
- If time permits, students should construct a successive approximation converter, using a simple comparator and D/A converter.
- It is not necessary to analyse the waveforms in detail.
- Students should identify the important performance criteria.

3.4 Important concepts are the same as those in 3.3.

- The class should analyse the operation of at least one commercial ADC unit, calculating speed, resolution, and cost.
- The class should study the programming for a successive approximation converter, in order to understand how it operates and why most commercial ADCs are of this type.
- Comparison of performance can be made using manufacturers' data, if necessary.

3.5 Important concepts are transduction, temperature coefficient, piezo-electric effect, Hall effect, and motor principle.

- Transducers should be introduced into the D/A and A/D circuitry as required. No particular order is suggested; nor should the study be extensive.
- Hall field effect devices may be linear or digital.
- The simulation of industrial control situations should be given priority.

3.6 Important concepts are design, and industrial control systems.

- This objective provides abundant opportunities for problem solving and creative effort. A good design at this point will call on all the technical knowledge and techniques that have been acquired in units 2 and 3.
- A good design solution by a student indicates subject mastery.

4.1 Important concepts are data communications, code conversion, and protocol.

- The interfaces should be driven with a computer output port or with a bit generator.
- The elementary protocol that is present in the UART requires a pair of signals.

4.2 Important concepts are data base, network, multiplexing, and demultiplexing.

- The teaching approach here can be based on a set of questions that lead students progressively to an understanding of the functional capabilities of computer networks.
- The teacher should discuss and demonstrate a simple star network, a database network, a local, and a general-purpose network.
- Information items and articles that clarify terms and concepts related to computer networks should be gathered from current trade literature and maintained as a continually updated reference source.
- This unit provides excellent examples of hardware-software trade-offs. The present trend is for software to take over many hardware functions.

4.3 Important concepts are modulation, demodulation, baud rate, modem, and transmission media.

- Access to a telephone line is required for demonstrations related to objective 4.3.
- Ideally, two telephone lines will be available in one room, with a computer connected to each. With this set-up, students can see the full transmission loop in operation.

5.1 Important concepts are information search, technical report, and communication of ideas.

- The ideal project provides a balance between hardware and software elements.
- *A technical report is mandatory*; presentation of the report to the class is optional, or at the discretion of the teacher.
- Students must give proper credit to their sources of information and quotations.
- Most projects will require students to make an *organized search* through technical literature. Students should also seek information or advice directly from experts or professionals.
- In some cases, students may be authorized to work in pairs, or even small groups, on a particular project. The teacher must, however, establish some equitable method of evaluating each student's contribution.
- The teacher should offer guidance regarding the scope of a project. A project should not be so big that the student cannot finish it.

Analog and Digital Electronics

This guideline provides authority for offering a single-credit Ontario Academic Course (OAC) in the technological studies field of analog and digital electronics.

Although electronics is a very broad field of study and application, almost all electronics involves the manipulation of electrons in order to do useful work. *Analog electronics* refers to those situations in which voltages and currents may assume a theoretically infinite range of values that are altered incrementally, often very rapidly. *Digital electronics* is used to describe those circuits in which only two voltage or current states (on-off) exist; all digital circuitry operates on this binary principle.

Over the past seventy-five years, the field of electronics has developed phenomenally. Today the pace of change within the industry continues to increase, spurred by the development of integrated circuits of greater and greater complexity. The range of applications of digital circuit technology has grown particularly rapidly in the past two decades, and all students who undertake a study of electronics must become familiar with this sphere of activity.

This OAC provides university-bound students with opportunities to test their interest in and aptitude for electronic technology. The electronic skill and knowledge that students acquire through this OAC will give them insights into the many diverse applications of the technology that they will encounter in their future studies and in their professional lives in engineering, science, and industrial design. Since electronics is in many ways an exact technology in which an infinite variety of applications is possible, students will have opportunities to develop disciplined mental habits and to learn problem solving of a most creative kind.

The prerequisite for this OAC is mathematics, Grade 11, advanced level, or its equivalent. In addition, students should have acquired, or should be prepared to acquire independently, some knowledge of basic electricity. A course in physics, electricity, or electronics would provide the required background.

The course code for Analog and Digital Electronics is TED0A.

Aims

Students who enrol in this course will have the opportunity to:

- acquire basic skills and knowledge in the technological field of analog and digital electronics;
- test their aptitude for and interest in the field;
- acquire background for studies in engineering, science, and design;
- develop the processes of logical thinking and creative problem-solving through the design of systems in applications of electronics;
- learn the disciplined procedures required for adaptation and operation of electronic devices in scientific apparatus and engineering systems;
- hone their skills of written and oral communication, critical thinking, and independent study through project work in electronics.

Suggestions for Planning the Course

The minimum time required to accomplish the objectives of this course is 90 hours. Additional selections from the optional content in unit 5 and optional learning activities indicated in the "Teaching Notes" (beginning on p. 17) can make up the remainder of the course.

This course involves the student in a mix of theoretical study and practical learning experience. Regular laboratory classes of at least one hour's duration should be provided.

Each student is expected to complete at least one term paper that involves independent study and creative effort. This should be on a subject of particular interest to the student, such as the application field he or she selects in unit 5.

Good safety habits must be an ongoing consideration in all laboratory activities related to the course. Suggestions included in Part A

of this guideline, in the section entitled "Safety" (p. 18), should be adopted wherever possible. In particular, students should be familiar with procedures followed by the school in emergencies associated with electrical shock, fire, toxic chemicals, and burns.

Course Content

For a detailed discussion of how to use this section, see pages 1-2 of this manual.

Overview

Content Units	Course Time (in hours)
1. Basic concepts and techniques	8-12
2. Semiconductor devices	14-20
3. Communications	8-10
4. Digital electronics	30-38
5. Applications	30-48

Objectives

1. Basic Concepts and Techniques

Students will have the opportunity to:

1.1 perform and explain experiments in electrostatics;

1.1.1 review the basic structure of matter;
1.1.2 describe, in qualitative terms, the forces between electrostatic charges;
1.1.3 differentiate between conductors and insulators, and categorize materials and substances as conductors or insulators;
1.1.4 define the unit of electrical charge;
1.1.5 state, in mathematical terms, the law of electrical charges;

1.2 review the concepts and units of potential difference, currents, resistance, and power and their relationships in AC and DC resistive circuits;

1.2.1 identify sources of electrical energy;
1.2.2 differentiate among sources, loads, and control devices;
1.2.3 describe the construction, characteristics, and colour codes of various resistor types, both fixed and variable;
1.2.4 discuss the generation and properties of AC waves;
1.2.5 analyse circuits quantitatively, confirming calculations by measuring;

1.3 analyse the behaviour of reactive elements in AC circuits;

1.3.1 describe the physical and electrical properties of inductors and capacitors;
1.3.2 examine the behaviour of capacitors and inductors under DC and pulse conditions;
1.3.3 examine the behaviour of capacitors and inductors under sinusoidal waveform conditions;
1.3.4 describe the physical and electrical characteristics of transformers;

1.4 develop techniques and skills in the proper use of tools and measuring equipment commonly used in electronics;

1.4.1 review precautions and procedures related to human safety while doing practical work in electronics;
1.4.2 practise the proper procedures for using electronic test equipment;
1.4.3 properly calibrate, adjust, and make measurements with a dual-trace oscilloscope;
1.4.4 properly solder wires and components in various physical situations;
1.4.5 select the appropriate wire for a given application;
1.4.6 select and use the appropriate hand tools for assembly and disassembly of electronic equipment;
1.4.7 identify the advantages of various types of circuit boards; design and make a simple circuit board; repair damaged boards;
1.4.8 translate schematics into actual working circuits;
1.4.9 identify typical stages, from design to production, in the development of a working circuit;
1.4.10 construct circuits that incorporate a variety of discrete passive devices.

2. Semiconductor Devices

Students will have the opportunity to:

2.1 analyse the operation of a filtered and regulated power supply;

2.1.1 describe the physical and electrical characteristics of a semiconductor diode;
2.1.2 determine, experimentally, the current-to-voltage (I-V) characteristics of a semiconductor diode;
2.1.3 observe, and explain the operation of, the common rectifier circuit configurations;
2.1.4 analyse the operation of a regulated power supply by observing and measuring all pertinent voltages and waveforms;

2.2 investigate the operation of a common emitter amplifier;

2.2.1 describe the physical and electrical characteristics of a bipolar transistor;
2.2.2 study and discuss the three basic transistor configurations;
2.2.3 using proper symbols and terms, draw the schematic diagram of a common emitter stage, showing the bias voltages and input and output connections;
2.2.4 interpret solid state specification sheets;
2.2.5 determine, experimentally, the frequency response and power gain of a typical RC coupled amplifier;

2.3 analyse the operation of circuits that include one or more of the following devices: operational amplifier, filter, optocoupler, transistor switch, thyristor;

2.3.1 build, and analyse the operation of, an operational amplifier as a comparator, an inverting amplifier, and a non-inverting amplifier;
2.3.2 build, and verify the operation of, an active filter circuit;
2.3.3 build, and verify the operation of, an optocoupler;
2.3.4 compare the operating characteristics of thyristors and switching transistors.

3. Communications

Students will have the opportunity to:

3.1 build and test an amplitude-modulated transmission/reception system;

3.1.1 describe, using a block diagram, the essential elements of a communication system;
3.1.2 explain the factors affecting successful transmission/reception of radio waves;
3.1.3 demonstrate amplitude modulation of a carrier;
3.1.4 sketch and label a chart depicting the electromagnetic spectrum, identifying those frequency bands that are used for the transmission and reception of intelligence;

3.1.5 demonstrate AM radio reception while describing the effects of such pertinent factors as selectivity, sensitivity, detection, and reproduction;
3.1.6 observe, using an oscilloscope, the waveforms that are produced throughout the whole system.

4. Digital Electronics

Students will have the opportunity to:

4.1 use basic logic devices efficiently in circuits;

4.1.1 distinguish between digital and analog devices;
4.1.2 identify the conventional logic gates by their symbols, and explain the function of each;
4.1.3 relate truth tables and Boolean expressions to combinational logic;
4.1.4 from a word problem, derive a Boolean expression;
4.1.5 from a truth table or Boolean expression, derive Karnaugh maps;
4.1.6 from Karnaugh maps, build and test the simplified circuit;

4.2 design and build a digital system such as an alarm system or a code converter;

4.2.1 develop the complete truth table for the word problem;
4.2.2 making use of Karnaugh maps, derive the simplest solution (solving for 1's and 0's and "don't care" states);
4.2.3 build and test the circuit corresponding to the simplest solution;

4.3 build and test a three-decade frequency counter;

4.3.1 investigate the operation of binary-coded-decimal (BCD) counters to verify BCD code for the ten decimal digits and identify methods for connecting BCD counters to form multidigit decimal counters;
4.3.2 analyse the operation of a seven-segment display;
4.3.3 investigate the use of a BCD-to-seven-segment decoder/driver in forming the appropriate numeral for a given BCD code;
4.3.4 use a decade counter to feed a BCD-to-seven-segment decoder/driver;
4.3.5 use debounce switches and an astable multivibrator as an event generator for the decade counter;
4.3.6 recognize the flip-flop (or latch) as a memory device, and describe its role in the frequency counter;
4.3.7 using a block diagram, describe the essential elements of a three-digit frequency counter;
4.3.8 describe the nature of multiplexing;
4.3.9 compare various clock generators;
4.3.10 analyse experimentally the operation of a signal conditioner;
4.3.11 build, and analyse the operation of, the control logic of a frequency counter;

4.4 build and test a microprocessor-based or microcomputer-based project that incorporates sensing of a condition or state and control of an external device;

4.4.1 investigate the use and operation of an interface adapter;
4.4.2 access a computer port using a programming language appropriate to the microprocessor being used;
4.4.3 build and test a D/A or A/D converter.

5. Applications

Sample assignments are listed in this unit for each of eight application fields. The teacher may add additional assignments that are suited to local conditions or resources. Students should investigate and study at least two of the fields of application. Each student is required to complete one project assignment individually. The additional project(s) may be undertaken by pairs or small groups of students. At least one of the assignments should involve a design-and-build or build-and-test element.

Students will have the opportunity to investigate, report on, and, where appropriate, design and build a project related to two of the following application areas:

5.1 fibre optics;

5.1.1 students explore the transmission through fibre optics of amplitude-modulated and digitally modulated signals;

5.1.2 students explore coupling methods and characteristics of optical fibres;

5.2 communications;

5.2.1 students do investigative research and write a report concerning a communication system, such as telephony, satellite communication, radar, or navigational aids;

5.3 industrial process control;

5.3.1 students do investigative research; design and build a project that demonstrates industrial process control of temperature, pressure, speed, position, etc.;

5.4 microcomputers and microprocessors;

5.4.1 students investigate, design, build, and test interfacing circuitry that performs a useful task when connected to a microprocessor or microcomputer;

5.5. audio/video systems;

5.5.1 students do investigative research and report on the state of the art of audio/video systems;

5.6 medico-electronics;

5.6.1 students investigate present and potential uses of electronically based medical diagnostic and treatment devices and equipment;

5.7 security systems;

5.7.1 students investigate and report on, using schematics, sophisticated security systems used in the home, in commercial establishments, and in industry;

5.7.2 students design, build, and verify the operation of a status indication circuit (send, receive, fail-safe, bad-signal indication, and alarm capability);

5.8 satellite communications;

5.8.1 students do investigative research and write a report on satellite communications. The project should include the following activities:
- drawing a block diagram of a satellite TV ground receiver system;
- designing a TV antenna (parabolic type) and determining aiming data according to satellite and receiver locations;
- investigating frequencies used in satellite communications.

Teaching Notes

The numbers of the teaching notes correspond to the numbers of the objectives in the preceding subsection. The suggestions that precede 1.1 are of a general nature.

- Professional persons from industry, colleges, or universities should be invited to provide additional technical and career information to students enrolled in this course.
- Field trips to local plants, technical shows, and research institutions can be useful. Destinations should be carefully selected, however, to ensure a profitable use of time.
- Students should be made aware of the legal and ethical issues connected with patents and copyrights.
- Institute of Electrical and Electronic Engineers (IEEE) standards and conventions should be followed, especially for symbolic language and dependency notation. A listing of IEEE standards is obtainable (at no charge) from IEEE Canadian Region Office, 7061 Yonge St., Toronto, L3T 2A6.
- Teachers should be on the lookout for resource materials such as textbooks, kits, films, CAI, and magazine articles that can support the various units of the course.

1.1 The important concepts to develop and reinforce are structure of matter, electric charge, electric field, potential difference, and conductors/insulators.

- Objectives 1.1 and 1.2 are a review for most students. Very little class time should be devoted to this content; a total of one hour is suggested.
- Students who have minimal background in basic electricity should be directed to good reference material.

1.2 Important concepts are generation of electrical energy, EMF, force-flow-resistance relationships, quantitative analysis, and conversion of energy.

- Properties of AC waves that should be defined and demonstrated are: frequency, sinusoidal, period, RMS, effective, peak, and peak-to-peak.

1.3 Important concepts are capacitance, inductance, magnetic field, electromagnetic induction, efficiency, and isolation.

- The students should breadboard an AC circuit incorporating a step-down transformer along with various combinations of inductance, capacitance, and resistance. The teacher should help them to analyse these circuits by calculation and by measurement.

1.4 Important concepts are safety, calibration, accuracy, precision, estimating, disciplined technique, and systematic fault finding.

- Safety glasses should be worn when soldering; wet sponges should be avoided.
- Disciplined technique and the use of common sense should be stressed.
- Although the skills related to this section are not primary objectives of this course, some drill in their development will result in more efficient use of time throughout the course.

2.1 Important concepts are rectification, filtering, and regulation.

- The mode of construction of the power supply will depend on the degree of permanence desired; it can be breadboarded, mounted on a perf-board, or soldered using a printed circuit board.
- If the construction is permanent, these units can be reused by later classes.
- Using only solid state components, students should progress from a half-wave configuration, with one capacitor for filtering, to the full-wave with pi filter. As a final step, they should incorporate a regulator in a variable-voltage supply.
- After studying the full-wave rectifier circuit, students should have little difficulty in analysing the operation of the bridge rectifier circuit.

2.2 Important concepts are amplification, biasing, coupling, frequency response, impedance matching, and power gain.

- Each student should build a one-stage transistor amplifier. If time permits, students should progress to a two- or three-stage amplifier with an FET input and complementary pair output, with the voltage amplifier in between.
- Students should realize that the main purpose of the FET is to provide high input impedance, while the complementary pair provides power gain.
- Prewired units may be used for the three-stage amplifier.
- This subunit offers scope for the correct use of several test instruments and for the construction of readable graphs that portray frequency response at various power levels.
- Students should learn how to read commercial (high fidelity) amplifier specifications.
- Demonstration and analysis can be done with the whole class or with small groups.

2.3 Important concepts are amplification, negative feedback, virtual ground, signal inversion, impedance, opto-isolation, and switching.

- One circuit that can incorporate all of the important concepts in this section is the colour organ. Several versions of this circuit have been published, some with active filters (if time is limited, only one channel need be constructed).
- Students should realize that, depending on the configuration, the input impedance of an op-amp may be high or low.
- The students should be able to differentiate between open-loop and closed-loop gain.
- If a colour organ is built, a 12-volt (rather than 120-volt) AC supply should be used for safety reasons.

3.1 Important concepts are communication system, modulation/demodulation, selectivity, sensitivity, electromagnetic transmission/reception, and reproduction.

- Students should build either a radio frequency system (using one modulated transistor stage as transmitter and a tuned circuit and diode as receiver) or a light system that utilizes an op-amp and LED in the transmitter, and a photoresistor and op-amp in the receiver.
- The phenomenon of resonance must be studied at this time.
- Students usually appreciate being able to modulate a transmitter with their own voice rather than solely by an audio generator.
- Inexpensive fibre-optic kits are readily available.
- If the radio system is built, there may be interference problems.
- Students should be aware that there are thousands of weak EM signals present in the room, making the sensitivity and selectivity demands critical for successful reception of *one* signal.
- Demonstration of the quantity and kinds of radio transmissions that fill the spectrum can be achieved if a communications receiver is available.
- Frequency modulation should be explained and demonstrated.
- Students should be informed that radio transmissions are subject to government regulations.

4.1 The important concepts to be introduced and/or reinforced as part of this objective are analog and digital operation, logic functions, gating, combinational logic, number systems, symbology, mapping, and efficient design.

- Up to this point, course content has been almost exclusively concerned with analog components, devices, and systems. The teacher should take the time to stress the difference between analog and digital, giving several examples of each and making sure that students understand.
- Because it is technically the most correct, bubble convention (assertion level) should be used.
- The three basic logic gates (AND, OR, and INVERTER) should be explained before the class progresses to the NAND, NOR, etc.
- Logic simplification is highly desirable, but practical implementation may be achieved using available ICs.

4.2 Important concepts are coding, encoding, decoding, mapping, and simplification.

- The word problem for the alarm system could be as follows: A fire protection system comprises two fire stations (a red and a green) and fifteen alarm boxes (identified by the letters B to Q). A logical 1 triggers an alarm bell at the appropriate station when an alarm box is activated. Note that there are two fire stations and that either or both may receive the alarm. Consider only the alarm boxes in your system (1 to 5). The other alarm boxes are non-existent (don't-care status). Design a decoder using 7400 gates to alert the proper station.
- The word problem for the code converter could be as follows: Design and build an 8421 to 2421 BCD code converter,

using the least number of packages. The following is a partial truth table for the BCD codes:

Dec.	8421 (DCBA)	2421 (ZYXW)
0	0000	0000
1	0001	0001
2	0010	0010
3	0011	0011
4	0100	0100
5	0101	1011
6	0110	1100
7	0111	1101
8	1000	1110
9	1001	1111

- It is suggested that these projects be done on a prototype board.
- This project is proposed because it is a good application of all aspects of Karnaugh mapping.

4.3 Important concepts are sequential logic, pulse shaping, counting, latching, resetting, clocking, multiplexing, debouncing, symmetry and asymmetry, synchronous and asynchronous, and scaling.

- Starting with a single-digit decoder/driver (a 7447 to seven-segment display), the class can investigate the concept of alternate display methods. Multiplexing can be introduced as additional decoder/drivers are added.
- A colour TV crystal and an MM5369 divider can be used to derive a very accurate time base for a frequency meter. A 555 timer can also be used as an astable multivibrator, which can be adjusted by input of a 60-Hz signal.
- The 7490 counter, the 7475 latch, the 7447 decoder/driver, and a common anode LED display can be breadboarded to teach the basic concepts of counting, latching, and decoding in a counter.
- Several suitable frequency counter circuits have been published. The teacher should select one that is relatively easy to wire.
- Since this circuit is the most complex to this point, the class or group should analyse its operation.

4.4 Important concepts are interfacing, D/A and A/D conversion, machine and assembly languages, and closed loops.

- The capabilities of the peripheral interface adapter (PIA) that is incorporated into the microcomputer being used for this course can be best demonstrated if simple machine language programs are executed while the input and output ports are monitored. Students are not expected to build a PIA.
- The teacher should design a closed-loop system that utilizes simple A/D and D/A converters. The students should construct and test this circuit.
- An LM3924 coupled to a matrix encoder can satisfy the requirement of a single-chip A/D converter; an op-amp, a ladder network, and a few switches can be wired to produce a D/A unit.

5. Important concepts that apply to this whole unit are: research, design, technical report writing, and construction techniques.

5.1 A basic fibre optics system can be very simple. Inexpensive kits are available.

5.2 A report on satellite communications might include a block diagram of a satellite TV receiver, selection of an appropriate antenna, determination of the aiming data, and a listing of the frequencies used in satellite communications.

5.3 The many possibilities in this application field include a range finder built around an ultrasonic transceiver (using an LM1812 and associated components), a robotics application, programmable controllers, and environmental sensing and control.

5.4 A few suggestions in this area are: a bicycle trip ''computer'', a programmable thermostat, a programmable lock, and a stepping motor control.

Fluid Power and Control

This guideline provides authority for offering a single-credit OAC in the technological studies field of fluid power and control.

The use of fluid under pressure to transmit power and control the motion of components precisely is a relatively young technology. Even so, almost every one of today's manufactured products has been formed or handled by fluid power at some point in its production or distribution. Machines and equipment that rely on fluid power systems for their functioning are now a part of almost every industry, but particularly the manufacturing, construction, transportation, and natural resource industries.

The variety of applications for fluid power will grow in the future. One reason for this increase will be the expanded use of automation in manufacturing. Fluid power allows parts and products to be readily moved or manipulated between processes, automatically and remotely.

The term *fluid power* embraces both liquid (hydraulic) systems and air (pneumatic) systems. Depending on the application, pumps, piping, cylinders, fluid motors, and control are used in both types of systems. The potential for solving application problems with fluid power systems is limited only by the creativity, knowledge, and skill of the designer.

Enrolment in this OAC can serve a variety of purposes. It can help students plan careers by allowing them to explore their interests in and aptitudes for mechanical and industrial control fields. It can also give students knowledge and skills that will be useful in many different professions.

The prerequisite for this OAC is mathematics, Grade 11, advanced level, or its equivalent. In addition, students should have acquired, or should be prepared to acquire independently, knowledge of mechanics and fluids. Previous courses in science, with physics units related to these topics, would provide the desired background.

The course code for Fluid Power and Control is TME0A.

Aims

Students who enrol in this course will have the opportunity to:

- acquire basic skills and knowledge in the technological field of fluid power and control;
- test their aptitude for and interest in further studies in this field;
- develop the processes of logical thinking and creative problem-solving through the design of systems and applications of fluid power and control;
- acquire knowledge and skills in designing, constructing, and testing fluid power systems for specific applications;
- hone the skills of written and oral communication, critical thinking, and independent study through project work on fluid power and control applications.

Suggestions for Planning the Course

This course involves the student in a mix of theoretical study and practical learning experiences. Regular laboratory classes of at least one hour's duration should be included.

All students are expected to complete at least one term paper that involves independent study and creative effort. In preparation for the term paper assignment (objective 5.5), students should be informed early in the course that they will be required to select and complete a major project of this type.

The total time indicated for delivery of the five units of this course is 110 hours (the full time required to accomplish one credit). All of the units must be covered, although students may select a particular project for unit 5.

Although the units listed in the "Overview" section are designed to be taught in numerical sequence, for this course the order of units 2 and 3 may be reversed, or these two units may be taught simultaneously – that is, integrated. If the teaching order of these

two units is reversed, the indicated times for the units must also be reversed. If the two units are integrated, the total time should equal the combined time for the two units (52 hours).

The choice of strategy for delivering units 2 and 3 will be determined in most cases by available equipment and facilities. If the pneumatics unit is taught prior to hydraulics, considerable time should be spent on the concepts of pressure, force, cross-sectional area, volume, velocity, and displacement. In addition, the system design concepts identified in objectives 2.2.3, 2.3.4, 2.3.5, and 2.4.3 should be introduced as part of the pneumatics content. The related discussion of these objectives under the heading "Teaching Notes" should be considered.

The development of good safety habits is an important part of the laboratory work in this course. A discussion of safety is included in Part A of this guideline as a topic under "Program Requirements" and should be reviewed by teachers when they are planning this course. The following safety rules should become a part of the working habits, and should shape the attitudes towards safety, of all students who take the fluid power and control course:

- Wear safety glasses to protect against flying objects or fluid spray from ruptured lines.
- Do not wear loose clothing that could catch in rotating or moving parts.
- Do not operate controls in a reckless manner that might cause hydraulic shock and damage.
- Observe extreme caution when starting up equipment for the first time and after a modification has been made.
- Always use the proper tools for the job.
- Never use damaging blows or excessive force when disassembling or assembling fluid power equipment.
- If the system has an accumulator, be sure its pressure energy is released before it is serviced or modified.
- Prior to working on a system, open and lock out any electrical circuits to motors, controls, etc.
- Shore up or block cylinders and machining parts that may drop because of gravity.
- To relieve any residual pressure from a system, bleed fluid by cracking fittings with a rag over the joints until the pressure is zero.
- When disassembling a component part, be careful not to unload a spring force that may cause parts to fly.
- Do not overtorque bolts or other fasteners, because doing so may distort housings and affect internal moving parts.
- Be alert to hazards that may threaten the safety of others.

Course Content

For a detailed discussion of how to use this section, see pages 1-2 of this manual.

Overview

Content Units	Class Time (in hours)
1. Introduction	8
2. Hydraulic systems*	30
3. Pneumatic systems*	22

Content Units	Class Time (in hours)
4. Electrics	25
5. Fluid power design	25

**An alternative sequence is authorized for units 2 and 3 under "Suggestions for Planning the Course" (pp. 21-22).*

Objectives

1. Introduction

Students will have the opportunity to:

1.1 investigate the effect of applying an external force to an enclosed liquid;

1.1.1 verify Pascal's law;
1.1.2 investigate the concept of work relative to an hydraulic jack system;
1.1.3 note the advantages of hydraulic jack systems over simple mechanical systems such as the lever;
1.1.4 calculate the hydraulic circuit element sizes required to give specified system characteristics (in both metric and imperial units);
1.1.5 investigate, as a class, the relationships among force, pressure, cross-sectional area, and distance over which the force acts;
1.1.6 define and use correctly terms related to basic fluid power technology;

1.2 investigate the pressure-volume relationship of air in a manually actuated pneumatic cylinder by observing the gauge pressure for various piston positions;

1.2.1 state and verify Boyle's law, Charles's law, and Gay-Lussac's law;
1.2.2 relate the laws listed in 1.2.1 to resulting changes in pressure, temperature, and volume, when one of these variables is changed (for a quantity of compressed air confined in a cylinder).

2. Hydraulic Systems

Students will have the opportunity to:

2.1 observe the operation of an automobile hydraulic braking system;

2.1.1 identify the basic components of an hydraulic system: foot pedal (pump), master cylinder, check valves, and cylinders;
2.1.2 review and analyse the concepts of force multiplication, coefficient of friction, retarding torque, and mechanical advantage as they concern the braking system;
2.1.3 investigate the problem associated with air in the hydraulic brake system and the effect of the compressibility of air on internal forces;
2.1.4 identify the purposes served by a dual braking system;
2.1.5 calculate the stopping time and distance for a braked vehicle (given specific data);

2.2 use a basic hydraulic circuit, consisting of a simple pumping system, a direct relief valve, and a manual four-way two-position directional valve, to stroke a double-acting cylinder;

2.2.1 describe the function and operation of each of the system components;
2.2.2 use symbols correctly in the schematic diagram of this circuit;
2.2.3 construct and operate a simple hydraulic circuit from a schematic diagram and verify physical relationships;
2.2.4 identify possible applications for a double-acting cylinder;

2.3 investigate the basic hydraulic circuit in 2.2, expanded for an application such as a clamp and press operation;

2.3.1 describe the function and operation of fixed and variable displacement pumps; direct and pilot-operated relief valves; sequence valves; three-position directional valves; needle, check, and flow control valves;

2.3.2 describe, and suggest applications for, the following types of circuits: differential, speed control, regenerative, filter, intensifier, and pilot signal control;
2.3.3 use and interpret correctly the symbols for additional components introduced in this section;
2.3.4 analyse the methods used to select cylinders, valves, reservoirs, pumps, electric motors, and pipes for specific applications;
2.3.5 use supplier catalogues to select appropriate components for specific applications;

2.4 investigate the basic hydraulic circuit in 2.2, expanded for an hydraulic motor application such as a simple conveyor drive or a power hub on mobile equipment;

2.4.1 describe the function and operation of various types of hydraulic motors and the symbolic representation of hydraulic motors in schematic diagrams;
2.4.2 evaluate torque requirements, speed control, directional control, dynamic braking, and cavitation for specific rotary actuator applications;
2.4.3 determine input power and output power of a rotary motor and calculate the mechanical efficiency for a given condition;
2.4.4 design an hydraulic circuit for a simple application of an hydraulic motor;

2.5 design, construct, and test an hydraulic application, such as a conveyor drive and transfer system, requiring the use of both linear and rotary devices;

2.5.1 investigate additional component requirements such as heat exchangers, reservoirs, accumulators, fluid selection, seal selection, cylinder cushioning, and cylinder rod column strength;
2.5.2 draw the schematic diagram and perform the necessary calculations for the design of a specific hydraulic circuit.

3. Pneumatic Systems

Students will have the opportunity to:

3.1 design, construct, and test a pneumatic circuit application to control the movement of a work piece, utilizing single-acting cylinders and a directional control valve normally closed;

3.1.1 use symbols correctly in drawing a schematic that involves a single-acting cylinder and directional control valve 3/2;
3.1.2 describe the functioning and control of single-acting cylinders and directional control valves 3/2;
3.1.3 develop specification criteria for cylinder movement and control requiring the function of a directional control valve 3/2;

3.2 design a system to control, condition, and apply compressed air utilizing air compressors, receiver, air dryers, piping, filters, water traps, regulators, and lubricators;

3.2.1 calculate approximate cost of compressed air for a particular application (pneumatic energy cost);
3.2.2 describe the functioning and control of air compressors, receiver, air dryers, piping, filters, water traps, regulators, and lubricators;
3.2.3 develop specification criteria for filters, regulators, lubricators, piping, and water traps;
3.2.4 use correct symbols in schematics that involve air compressors, receiver, air dryers, piping, filters, water traps, regulators, and lubricators;

3.3 design a pneumatic system application for controlling the positioning of cylinder movements (single or double acting), using directional control valves, flow control and quick exhaust valves, sequencing, and safety devices;

3.3.1 use symbols in schematics that involve directional control valves, cylinders, flow control, non-return and pressure-regulating valves, and sequencing and safety systems;
3.3.2 describe the functioning and control of directional control valves, flow control, non-return and quick-exhaust valves, and sequencing and safety systems;
3.3.3 develop specification criteria for cylinder movements and control, which require the function of directional control valves, flow control, quick-exhaust valves, and sequencing and safety systems;

3.4 design a pneumatic system application in which a rotary actuator controls the positioning of a work piece;

3.4.1 use symbols appropriately to represent air actuators in schematic circuit diagrams;
3.4.2 describe the functioning and control of an air actuator;
3.4.3 develop specification criteria for air motor applications requiring various work loads (calculations to include air consumption);

3.5 design a sequence control system utilizing cascade or stepper circuits;

3.5.1 use symbols and motion diagrams appropriately in the development of schematics that involve sequencing systems;
3.5.2 describe the function of a cascade or stepper circuit;
3.5.3 develop specification criteria for sequencing systems utilizing cascade or stepper circuits.

4. Electrics

Students will have the opportunity to:

4.1 design an adaptation of a hydraulic or pneumatic circuit (previously covered) utilizing electric actuation;

4.1.1 describe the electromagnetic theory and operation of a solenoid actuator;
4.1.2 identify the effects on a solenoid of reduced voltage operation;
4.1.3 investigate and describe how solenoids may be used to actuate various hydraulic and pneumatic devices;

4.2 investigate and explain the operation of circuits designed to include a solenoid-actuated pilot valve on-off component;

4.2.1 investigate and describe the use of switches as AND and OR devices;
4.2.2 develop truth tables for various switch circuits;

4.3 investigate and describe the operation of circuits designed to use a pressure control or limit switch and relay to reverse an hydraulic or pneumatic actuator;

4.3.1 combine the solenoid concept with switches to form relays;
4.3.2 develop logic statements for relay circuits introducing the NOT, or inverting, concept of logic;
4.3.3 investigate and describe how a memory device may be illustrated by the electrical latching of a relay;
4.3.4 investigate and use ladder diagrams and the associated truth tables for analysis of electric control circuits;
4.3.5 investigate and use a transducer such as the pressure limit switch to feed information back to the logic devices;

4.4 investigate and describe the operation of circuit designs that utilize actuators controlled in sequence by relays and limit switches;

4.4.1 investigate the use of electric motors as power actuators, identifying various means of converting rotary motion to linear motion;
4.4.2 develop a comparison of factors such as voltage, current and power requirements, and electrical code and safety considerations to facilitate choices between AC and DC for particular applications of fluid power and control;

4.4.3 develop the truth table and ladder diagram for a circuit that utilizes actuators controlled in sequence by relays and limit switches (motion diagram provided by the teacher);

4.5 investigate the use of a torque motor as an analog device in circuit designs involving proportional control;

4.5.1 investigate and describe the operation of torque motors and flapper-nozzle systems as proportional control devices;
4.5.2 investigate and describe the interfacing of a microprocessor for computer control of a system;
4.5.3 identify and describe the role of feedback in the above circuits.

5. Fluid Power Design

Students will have the opportunity to:

5.1 compare the relative advantages of hydraulic and pneumatic systems for a variety of applications;

5.2 evaluate the advantages of electrical control for remote operation of fluid power systems;

5.3 develop the schematic for a circuit involving an electric relay and switch system to accomplish the control of a specific machine;

5.4 investigate, and prepare a brief report on, the potential of proportional control for sensing and operating the grip of a robot manipulator;

5.5 design, construct, and report on a fluid power solution to a particular problem.

Teaching Notes

The numbers of the teaching notes correspond to the numbers of the objectives in the preceding subsection. The two subsections should be used together in the planning of this course.

1.1 The concepts to be stressed in this section include force, pressure, work, efficiency, mechanical advantage, velocity ratio, inertia, and Pascal's law.

- The following equipment should be available for demonstration and class activity: hydraulic jack or hydraulic hand pump, cylinders, and connecting lines to construct a segregated jack.
- Terms that should be clarified in this section include: *fluid power*; *hydraulics; fluids (liquid, gas); pressure (gauge, absolute, working); compressibility; volume, flow, cross-sectional area; transmission; viscosity; velocity; cylinder, piston.*

1.2 Verification of the gas laws in this section need only be qualitative.

- Students can verify Boyle's law by using a pneumatic cylinder fitted with a pressure gauge and relating the enclosed volume to positions of the piston identified by exposed lengths of the piston rod.
- Pressure changes within the fixed volume of a closed pneumatic cylinder may be observed on a gauge as it is heated.
- The motion of the piston, as confined air in a pneumatic cylinder is heated, may be observed and related to volume change.
- Students may observe the cooling effect at an orifice as air is allowed to escape from a charged cylinder (a diving cylinder is one example).
- Students should be able to interpret the above effects in terms of the gas laws.
- Numerical problems related to pneumatic applications should be used to study quantitative aspects of the gas laws.

2.1 Concepts that require review and reinforcement in this section include force multiplication, compressibility, retarding torque, friction, safety backup system, and the system as an input and an output with control devices in between.

- Students should be able to draw a block diagram of an automobile hydraulic braking system and identify the main components.
- The nature, and relative effects on the braking process, of sliding, static, and rolling friction should be discussed.
- Students can calculate the stopping time with retarding torque and with wheels locked.

2.2 In this subunit, students should begin to develop fluid power language skills. They should be able to communicate specifics of fluid power hardware by symbols, and details of fluid power circuits by schematics. They should also be introduced to testing and verification procedures for fluid power applications.

- Students should be able to recognize and describe the functions of the following components: pumps (positive displacement and other types), reservoirs, pressure control valves, four-way/two-position directional control valves, double-acting cylinders, and prime movers such as electric motors and engines.
- Students may write a 300-word description of one application of this basic system.

2.3 Students should begin to build skills in technical referencing. They should acquire knowledge of the methods used to identify the fluid power components appropriate to specific applications, and they should learn to use supplier catalogues and manuals.

- The following valves may also be included in this section: relief, pressure reducing, sequence, unloading, counterbalance, two-way, three-way, and four-way manually operated valves; two-position valves and three-position valves – open centre, blocked centre, and tandem centre (other types of centres may also be considered).
- Students should have an opportunity to handle the various components.
- The exploratory work for this section should enable students to describe, with the help of schematics, the purpose, function, and sequence of operation of the following seven circuits:

1) meter-in circuits using check and flow-control valves (describing probable use, such as press or forming system);
2) meter-out circuits using check and flow-control valves (describing probable use, such as saw or milling machine);
3) bleed-off circuits using flow-control valves (describing use and efficiency compared to first two systems);
4) regenerative circuits using the following:
   a) blocked port on directional control valve;
   b) check valve and sequence valve;
   c) check valves and flow-control valve;
5) intensifier circuits using tandem cylinders in parallel for fast approach and high force with replenishing line (describing merits of the system in general tube testing, and advantages of air over oil systems);
6) filter circuits (discussing pressure line, return line, suction line, and relief valve systems and the merits of each as well as sizing, types of elements, and maintenance considerations);
7) pilot signal control (discussing how system pressure is used to actuate, by feedback, control valves such as relief valves, unloading valves, and sequence valves).

- To determine the appropriate sizes for components in a system under development, students should be able to:

  1) calculate the volume required, given bore and stroke of the cylinder and cycles per minute (volume to be in litres per minute and gallons per minute – based on 231 in.^{3}/gal.);
  2) determine, for the system described in (1), the necessary system pressure for a given required force;
  3) calculate, for a given fluid velocity in the circuit, considering equation of continuity, laminar flow, turbulent flow, hydraulic radius, and hydraulic gradient, diameters of line required using Chezy-Darcy approach or Hazen-Williams approach;
  4) calculate, for a determined pressure in a system, the proper pipe wall thickness to withstand the hoop stress occurring as a result of line and surge pressures (considering design, service factors, tensile strength, and yield strength calculations made by Bordman hoop formula);
  5) determine the power requirements of the prime mover in a fluid power system, given the pressure and volume equation (from the work principle);
  6) determine the accumulator size (for auxiliary or main power source) required for one function in a circuit, using Boyle's law to determine size and precharge pressure (considering isothermal solution);
  7) determine, from catalogues and other literature, the pump size needed to handle the system.

2.4 Concepts that are introduced and reinforced in this section include: rotary motion and relationship to linear motion, power (with unit considerations in both SI and imperial systems of measurement), mechanical efficiency, and control.

- The exploratory activities related to rotary drive systems should enable students to:

  1) describe with the aid of a schematic a simple one-way transmission drive system;
  2) describe hydraulic motor principles, showing how torque is delivered from the motor (considering pressure and displacement), and develop the formula for torque;
  3) discuss the types of hydraulic motors in use (piston, gerotor, gear, vane, and screw) and discuss and describe sizing of hydraulic motors;
  4) describe with a schematic diagram a forward and reversing circuit using a four-way, two-position directional control valve;
  5) describe with a schematic a forward, reverse, and stop circuit using a four-way, three-position valve, considering an open centre and tandem centre spool;
  6) describe with a schematic a forward, reverse, and dynamic braking system using check valves and relief valve to allow a replenishing circuit back to motor.

2.5 Concepts that should be studied in this section include transferring (such as in conveyors and other systems); heat and heat exchanging; cushioning of cylinders; and stress – tension, compression, bending (buckling), and shear.

- In their investigation of stresses, students should study Hooke's law and use the modulus of elasticity in typical calculations. As well, students should consider the effects on these stresses when different materials and surface finishes are used and when dimensions such as cross-sectional area and length are varied. These stresses may also be considered in relation to various types of

mounting. Supplier catalogues and manuals can be used as resources for investigating stresses in various components.

- Exploratory activities related to reservoir design and specification criteria should examine the following: fluid volume for system requirements, surface area for heat transfer within the tank, settling, air escape, hot fluid expansion, minimizing cavitation, location, construction, baffling, heat load, and film coefficient.
- Students may examine a variety of fluid types (petroleum base, phosphate ester, water, water-glycol, and high water base fluids) and consider the requirement for filtration (suction, pressure, and return line).
- The discussion of hydraulic fluids should include hydraulic oil properties, i.e., lubricity, oxidation, pour point, and viscosity index.
- A transparent tank may be used to demonstrate discharge into the tank from a hose or pump. The action of movable baffles may also be demonstrated in a reservoir of this type.
- For a given set of conditions, students may be required to perform the calculations of volume and heat transfer needed to correctly specify the reservoir.
- Exploratory activities related to heat exchangers should provide the student with knowledge of their purpose and of the different types, such as shell and tube, multiple pass, and water and air cooling. Students should be able to define and use correctly terms denoting the physical principles associated with heat exchange, including *conduction, convection, heat transfer coefficients, scale coefficients, specific heat, thermal conductivity,* and *units of heat*. Students may also be required to demonstrate a method of calculating the size of a heat exchanger for a given application using a water-cooled system.
- Considerations related to cylinder design may serve to introduce cylinder rod sizing and cushioning. The various types of cylinders, such as double rod-end, ram, telescoping, cable, diaphragm, tandem, and duplex, may be identified. Mounting systems and standards may be considered. Aspects of cylinder body construction such as tie-rod, mill, one-piece weld, and centrifugally cast may be identified. Cushion designs such as spear, stepped, and piccolo may be analysed, and aspects of cylinder rod size may be considered for various applications in terms of column strength, susceptibility to buckling or rod bearing failure, and requirements relative to compression and tension forces.
- The discussion of seals and packing should cover properties of principal elastomers used for fluid power seals, the compatibility of sealing material with the medium used, and types of seals (O-rings, V-rings, cup seals, packing types, and functions).

3.1 Pneumatic systems can be effectively introduced through analogy and comparison with the hydraulic systems.

- The concept of directional control can be further explored and reinforced in this section.

3.2 The concepts of pneumatic energy and relative humidity should be studied in this section.

- Techniques and requirements for lubrication and conditioning of air should be explored through laboratory activities.

3.3 Topics that require reinforcement in this section are linear positioning control, sequencing of events, and operator and equipment safety.

- It is extremely important that students be made aware of the hazards associated with improper use of compressed air and instructed in the proper procedures for utilizing this energy source.

3.4 The concepts of torque, rotary speed, and control of rotary position should be emphasized in this section.

3.5 Investigation of the concept of pneumatic memory should include a study of pneumatic relay stepping, bi-stable devices, switching, and graphical representation of time/step sequence.

4.1 Electromagnetic fields and forces should be investigated in this section. The investigation should include electric and magnetic circuits, flux density, solenoid function, measurement of voltage, current, power, and pulling force of a solenoid.

- The concept of actuation as a predetermined action should also be reinforced in this section.

4.2 Students should be introduced to logic elements and the use of truth tables for circuit design and analysis.

- A brief introduction or review of Boolean algebra should be included.

4.3 Concepts to be studied in this section include inverting logic (NOT), latching, and feedback.

- The use of ladder diagrams to represent sequence operation has application in other subject fields.
- The concept of a transducer, which senses a physical quantity and presents it in a form that can be transmitted electrically, should be discussed for a range of devices. Temperature, pressure, level of liquid, and force (strain gauge) are only a few of the possible examples.

4.4 The electrical code and standards should be discussed in this section. It is essential to take safety precautions when applying electric motors as power actuators.

- The concepts of fluid power and the conversion of rotary motion to linear motion can be further studied in this section.

4.5 The concept of proportional control is examined with only one technique in this section. Students should be made aware that there are alternative techniques.

- Interfacing a microprocessor for control of a fluid power system requires an understanding of analog and digital signals and their conversion.

5.5 This final project should provide the student with an opportunity to review and apply all the knowledge and skills acquired in the course. A minimum of fifteen hours of class time should be allowed for the project. Out-of-class information research, problem solving, and creative design can be expected to consume another fifteen hours of students' time. All phases of the project – not simply the final product and report – should be considered in the evaluation.

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